# Effectiveness of exercise-based sports injury prevention programmes in reducing injury rates in adolescents and their implementation in the community: a mixed-methods systematic review

Zhe Xin Zhang (1), <sup>1</sup> Joseph Lai (1), <sup>2</sup> Liang Shen (1), <sup>3</sup> Lingaraj Krishna (1), <sup>4,5</sup>

#### **ABSTRACT Objective** Despite evidence supporting the efficacy

community.

settings.

INTRODUCTION

of sport injury prevention programmes (SIPPs) in

adolescents, implementation of SIPPs in community

integrate evidence on the efficacy of exercise-based

implementation strategies for such programmes in the

settings is low. This review aims to synthesise and

SIPPs in reducing injury rates in adolescents with

**Design** A systematic review with meta-analysis,

conducted, followed by a convergent segregated

approach to integrate the findings. Sensitivity and

subgroup analyses were conducted. Study appraisal was

**Data sources** Literature search of nine databases was

carried out to identify studies in English from January

controlled trials (RCTs), qualitative or mixed-methods

Interventions included SIPPs. Outcomes were injury

rate and rate ratio (IRR). Phenomena of interest were

Results 23 studies were included for analysis. Meta-

SIPP (IRR 0.63, 95% CI 0.53 to 0.74, p<0.00001) in

adolescents. Meta-aggregation of seven qualitative/

findings that impact implementation namely players'

organisational support and characteristics of the SIPP.

**Conclusion** Implementation of SIPPs provides a 37%

approach for its efficacy to be translated. Future research

implementation strategies in adolescents in community

Rise in popularity of sports from younger age

Active participation in sports from young both

recreationally and competitively is increasing

worldwide, becoming an integral part of the life of

many adolescents.<sup>12</sup> This is shown to also translate

to a higher level of physical activity (PA) when older,

promoting a lifelong active lifestyle.<sup>3</sup> Living a phys-

ically active lifestyle from young brings important

perceptions and beliefs, coaches as key facilitators,

risk reduction in adolescents but requires targeting

key stakeholders through a top-down multifaceted

should investigate the effectiveness of SIPPs and

mixed-method studies revealed four sets of synthesised

analysis for 16 RCTs showed a protective effect of

facilitators and barriers to the implementation of SIPPs.

studies. Population included adolescents (10–19 years).

performed using Joanna Briggs Institute Critical Appraisal

narrative synthesis and meta-aggregation was

Checklists and Mixed Methods Appraisal Tool.

Eligibility criteria Included were randomised

2012 to December 2022.

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<sup>1</sup>Alice Lee Centre for Nursing Studies, National University of Singapore Yong Loo Lin School of Medicine, Singapore <sup>2</sup>National University of Singapore Yong Loo Lin School of Medicine, Singapore <sup>3</sup>Biostatistics Unit, National University of Singapore Yong Loo Lin School of Medicine, Singapore <sup>4</sup>Orthopaedic and Hand Surgery Partners Pte Ltd, Singapore <sup>5</sup>Division of Sports, Shoulder & Elbow Surgery, Department of

#### Correspondence to

Zhe Xin Zhang, Alice Lee Centre for Nursing Studies, National University of Singapore Yong Loo Lin School of Medicine, Singapore, Singapore; zhexinnn@gmail.com

Orthopaedic Surgery, National

University Hospital, Singapore

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## WHAT IS ALREADY KNOWN

- ⇒ Sports injury prevention programmes (SIPPs) are efficacious in reducing injury rates in children and adolescents, but the adoption and sustainability of SIPPs in the community remain low.
- ⇒ SIPP implementation in adolescents is complex, and research is needed to better understand the implementation context and promote evidence translation.

## WHAT ARE THE NEW FINDINGS

- ⇒ This is the first review to synthesise qualitative evidence specifically regarding implementation of SIPPs in adolescents. Corroborating findings with results from quantitative analysis showing a 37% overall sports injury risk reduction reveals that key stakeholders at multiple ecological levels (organisations, coaches and players) need to be engaged to drive implementation in the community. The adaptability and user-friendliness of SIPPs also play a key role.
- ⇒ Due to the hierarchy of responsibility among stakeholders involved in adolescent SIPP implementation, a top-down approach to implementation would be most optimal, beginning at organisations that are best positioned to support and drive change and have downstream effects on other stakeholders.
- ⇒ Future studies should use findings from this paper to develop and apply implementation strategies targeted at key stakeholders and evaluate the effectiveness of SIPPs in community settings using the Reach Effectiveness Adoption Implementation Maintenance Sports Setting Matrix (RE-AIM SSM).

immediate and long-term health benefits such as better cardiorespiratory and mental health while improving neuromuscular fitness and decreasing future risk of chronic diseases.<sup>4–6</sup>

However, this is associated with an increased risk of sports injuries where the risk is highest during adolescence (ages 10–19).<sup>7 8</sup> Sports and PA are also the leading causes of injury in adolescents, accounting for >30% of all adolescents' injuries compared with just 9% of injuries in adults.<sup>6 9</sup> The increased intensity and frequency of sports training

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and competition from young in recent years contribute to this higher sports injury rate in adolescents.<sup>10</sup>

Sports injuries are associated with an increased risk of physical and psychosocial health issues.<sup>7 11</sup> Current and future participation in sports and PA decreases as a result, which leads to the loss of health benefits that come with an active lifestyle.<sup>7 12</sup> There are also substantial economic and individual consequences due to high costs of treatment and opportunity costs from possible extensive periods of immobility.<sup>13</sup> On a societal level, an increased burden is placed on public healthcare due to the higher volume of hospitalisation and the various resources required for injury treatment.<sup>14</sup> Hence, finding ways to reduce the sports injury rate in adolescents is of utmost priority.<sup>4</sup>

# Importance of starting sports injury prevention from adolescence

Emery *et al*<sup>6</sup> suggest that while it is not possible to entirely prevent sports injuries in adolescents, effective exercise-based Sports Injury Prevention Programmes (SIPPs) can reduce the rate and severity of sports injuries. This has many downstream benefits like reducing the various costs mentioned.<sup>11 15</sup> Injury prevention efforts are also recommended by Myer *et al*<sup>16</sup> to be started from adolescence to maximise efficacy as it was discovered in their meta-analysis that the age of the athlete affects the efficacy of SIPPs in reducing anterior cruciate ligament (ACL) injuries.

#### Rationale for this mixed-methods review

While there are four similar reviews on the efficacy of SIPP in reducing injury rates involving adolescents, there are some key differences from this review in terms of the target population.  ${}^{46}$   ${}^{11}$  This review looks at adolescents only in all sports but the reviews by Ding *et al*<sup>17</sup> and Rössler *et al*<sup>4</sup> looked at not only adolescents but children too, while Soomro *et al*<sup>11</sup> and Emery *et al*<sup>6</sup> limited studies to team sports. Ding *et al*<sup>17</sup> also restricted SIPP to warm-up exercises only.

Despite the multitude of scientific evidence collated in the systematic reviews supporting the efficacy of SIPPs in adolescents, implementation in real-world settings and actual public health impact remains limited. <sup>18–20</sup> The injury rate among adolescent athletes continues to rise and many studies have shown that SIPPs are still not part of training routines and sports practices across various populations.<sup>7 21 22</sup>

This lack of adoption of SIPPs for adolescents highlights a necessary change in research focus and methods.<sup>20</sup> Understanding the factors that support and inhibit the long-term adoption of SIPPs in target populations from different perspectives by examining qualitative literature is important in influencing behavioural change in adolescents and stakeholders and reducing the research-to-practice gap.<sup>18</sup> <sup>19</sup> <sup>23</sup> Due to the complexity of sports injury prevention, multiple research questions and an integration of qualitative and quantitative evidence is optimal.<sup>24</sup> A mixed-methods approach broadens the scope of this review compared to previous systematic reviews by Emery et  $al^6$  and Soomro et  $al^{11}$ , allowing for a more in-depth exploration of injury prevention in adolescents.<sup>25 26</sup> It provides the opportunity to corroborate findings of SIPP efficacy with insights into the barriers and facilitators of SIPP implementation and maintenance, providing more meaningful evidence to inform SIPPs practice and policy in adolescents.<sup>27</sup> To the best of our knowledge, no such review has been conducted before on this topic.

### **REVIEW OBJECTIVE**

The objective of this mixed-methods systematic review is to update and synthesise evidence on the efficacy of exercise-based SIPPs in adolescents while integrating it with research on implementation context for injury prevention to promote evidence translation and improve effectiveness. This review seeks to answer the following review questions:

- 1. What is the efficacy of the various exercise-based SIPPs in reducing injury rates in adolescents in the community setting?
- 2. What are the facilitators (enablers) and barriers to the implementation of SIPPs in adolescents in the community setting?

#### METHODS

This systematic review was conducted in accordance with Joanna Briggs Institute (JBI) methodology for mixed-methods systematic reviews and reported following the updated Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 checklist.<sup>28</sup> <sup>29</sup> The study protocol is registered on PROSPERO (CRD 42023403096).

#### Information sources and search strategy

A search of six databases (PubMed, EMBASE, Cochrane Library, CINAHL (EBSCOhost), Scopus and Web of Science) was performed to identify relevant studies from January 2012 to December 2022. Google Scholar, ProQuest Thesis and Dissertations and ISRTCN were searched for grey literature. The reference list of all selected studies was also screened for additional studies not previously identified. Keywords and index terms were broken down into three groups: population, injury type and intervention, and used to develop full search strategies for each database which can be found in online supplemental file 2:appendix A.

#### Selection of studies

Inclusion criteria for quantitative component:

- 1. Participants were between 10 and 19 years old and participated in sports.<sup>8</sup>
- 2. SIPPs are exercise based and implemented across a minimum period of 3 months.<sup>30</sup>
- 3. Investigated outcomes related to sports injury (injury rate/ ratio (IRR) or total number of injuries).
- 4. Controls were either usual training/warmups, alternative forms of injury prevention or no intervention.
- 5. Only randomised controlled trials (RCTs) as it is the most ideal to examine the cause-and-effect relationship between interventions and measured outcomes.<sup>31</sup>
- Studies were excluded if adolescent age-group outcomes were unable to be separately extracted or incomplete. Inclusion criteria for qualitative component:
- 1. Studies that investigated barriers and facilitators in sports injury prevention in adolescents.
- 2. Is in the community setting.
- 3. Qualitative studies with study designs such as phenomenology, grounded theory, ethnography and qualitative descriptive. Mixed-methods studies where qualitative component can be clearly extracted.

Only English language studies were included due to the lack of reviewer proficiency in other languages and resource limitations. Since there were previous meta-analyses on the efficacy of SIPP in adolescents,<sup>6 11</sup> and it is only in the past decade that research emphasis has been placed on understanding the implementation of sports injury prevention,<sup>32–34</sup> only studies published from 2012 to 2022 were included to retrieve the most current

evidence of SIPPs efficacy and insights into its implementation for adolescents.

#### Data extraction and quality assessment

Quantitative data extracted included specific details about the populations, intervention characteristics and outcomes of relevance to review objective (online supplemental file 2:appendix C). Extracted qualitative data (findings) with their corresponding illustrations were assigned a level of credibility ('unequivocal', 'credible' and 'not supported') and grouped into themes. Authors of papers were contacted for additional or missing data, where required.

Assessment of selected studies was done independently by two reviewers (ZXZ and JL) using the standardised JBI Critical Appraisal Checklists for RCTs and qualitative studies.<sup>35 36</sup> The Mixed Methods Appraisal Tool (MMAT) tool was used for mixed-methods studies instead as JBI does not have a critical appraisal tool for it.<sup>37</sup> Disagreements regarding appraisal were resolved through discussion between both reviewers and with a third reviewer (LK) when consensus could not be reached. All studies, regardless of methodological quality, underwent data extraction and synthesis to consolidate all available evidence to enhance the rigour of the synthesis and provide further insights into sports injury prevention.<sup>38 39</sup>

#### Data analyses and synthesis

A mixed-methods convergent segregated approach was used for synthesis and integration.<sup>28</sup> Quantitative and qualitative synthesis was done separately followed by integration of the resultant quantitative and qualitative evidence (online supplemental file 2:appendix D).

#### **Quantitative synthesis**

Study data were pooled with statistical meta-analysis using RevMan V.5.4. IRR with 95% CIs was used to measure the effect size of each study. Natural logarithmic transformation of all IRR was conducted and the generic inverse variance randomeffects model was used for the statistical analysis.<sup>40</sup> Narrative synthesis was used to present outcomes when meta-analysis was not possible.

Subgroup analyses based on session duration, implementation strategies, intervention type, intervention focus and player compliance were conducted to help examine sources of heterogeneity and identify potentially influential moderating factors on the efficacy of SIPP.<sup>41</sup> Sensitivity analysis was also conducted to examine the source of heterogeneity. A funnel plot was generated using RevMan to assess publication bias.

#### **Qualitative synthesis**

Qualitative findings were pooled using the meta-aggregation approach that involves an iterative approach of categorising findings based on similarity in meaning.<sup>25</sup> These categories were subsequently synthesised to produce a comprehensive set of synthesised findings to be used as the basis for evidence integration.42

#### Integration of quantitative evidence and qualitative evidence

Through discussion by two reviewers, the quantitative and qualitative evidence was juxtaposed and organised into a line of argument to produce an overall configured analysis.<sup>28</sup>

Refer to online supplemental file 1:Methods for more detailed methods section.

#### RESULTS Study selection

The screening process is depicted in figure 1 using the PRISMA flow diagram.<sup>29</sup> An initial search yielded 9681 articles after duplicate records were removed. 9288 records were excluded based on title and 186 records based on abstracts when screened against the eligibility criteria. Eventually, the full text of 200 articles was retrieved and assessed for inclusion. Finally, 23 articles were included in this review after 177 articles were excluded for various reasons as outlined in figure 1.

#### Study characteristics

Of the 23 included studies, 16 were RCTs,<sup>43–58</sup> 5 were of qualitative methodology<sup>59-63</sup> and 2 were mixed-methods studies.<sup>64 65</sup> Š A table summary of all the studies and their characteristics can copyright be found in online supplemental file 2:appendix D. Among the 16 RCTs (1 is a 3-arm RCT), 9 of them looked at preventing all injuries, 2 focused on upper extremity and 6 on lower extremity injuries. In terms of SIPP content type, 12 of the studies featured comprehensive (multifaceted) SIPPs that contain a mixture of balance, plyometric, strength and neuromuscular control exercises while the other 5 were single-component SIPPs like stretching, strengthening or proprioception exercises only. Only ð three studies had a subanalysis on the effect of SIPP compliance on injury rates. Out of the seven qualitative and mixed-methods studies, six used either an implementation science framework or behavioural change model. related to text

#### Methodological quality

Summary tables of the critical appraisal using JBI checklists and MMAT for the respective studies are presented in online supplemental file 2:appendix E. For the RCTs, blinding for researchers and participants (Q4 and 5) was either unclear or not done for almost all the studies (87.5%). However, failure to blind is unlikely to affect the objective outcomes for SIPP studies as it is known that true researcher and participant blinding is incredibly difficult in injury prevention research.<sup>66 67</sup> Blinding of the outcome assessor was done in 8 of the studies while true randomisation was used in 11 of the studies and unclear in the other 5. Allocation concealment was unclear in five of the studies (31.3%).

J, Al training, The methodological quality of all the qualitative and mixedmethods studies is generally very high (all studies >80%). and similar technologies However, most of the qualitative studies did not elaborate on the cultural and theoretical position of the author (80% no or unclear) and authors' influences on the research (60% no or unclear).

#### **Ouantitative evidence: meta-analysis**

A meta-analysis was conducted on the SIPP effect on IRR of adolescents (figure 2). The pooled estimates suggest a significant overall protective effect of SIPP against sports injury in adolescents (IRR 0.63, 95% CI 0.53 to 0.74; Z=5.57, p<0.00001). However, substantial heterogeneity was detected among the included studies ( $I^2 = 65\%$ , p<0.0001). The heterogeneity could be due to the review including a bigger variety of participants, type of injury outcomes measured and type of SIPP.

#### Subgroup analyses

Subgroup analyses showed no statistically significant subgroup differences for player compliance (p=0.52), SIPP session duration (p=0.69), implementation strategies (p=0.38) and SIPP type (p=0.56), likely constrained by the small number of studies

. uses

Protected



Figure 1 PRISMA flow diagram.

and participants in some of the subgroups<sup>68</sup> (online supplemental file 2:appendix F).

Meanwhile, subgroup analysis (figure 3) on intervention focus revealed significant subgroup differences ( $I^2 = 76.9\%$ , p=0.01). Results suggest that general SIPP for all injuries (IRR 0.60, 95% CI 0.47 to 0.76; Z=4.18, p<0.0001) and upperextremity SIPP (IRR 0.47, 95% CI 0.34 to 0.65; Z=4.63, p<0.00001) has better protective outcome on sports injuries than lower-extremity SIPP (IRR 0.78, 95% CI 0.66 to 0.93; Z=2.76, p<0.00001). However, this larger injury protection effect should be interpreted with care as the upper-extremity SIPP subgroup has far lesser number of studies (two studies) included compared with the other subgroups, and substantial heterogeneity was also detected among the studies for all injuries SIPP subgroup ( $I^2 = 78\%$ ), suggesting that the validity of injury prevention effect is uncertain for this subgroup.<sup>68</sup> The same subgroup analysis also revealed homogeneity ( $I^2=0\%$ ) among the studies in both the lower-extremity SIPP subgroup

			Intervention	Control	Rate Ratio Rate Ratio		Rate Ratio
Study or Subgroup	log[Rate Ratio]	SE	Total	Total	Weight	IV, Random, 95% CI	IV, Random, 95% CI
Achenbach 2017	-0.2487	0.5864	168	111	1.7%	0.78 [0.25, 2.46]	
Åkerlund 2020	-0.4308	0.1139	301	170	9.2%	0.65 [0.52, 0.81]	
Asker 2022, Knee	-0.3711	0.1746	216	212	7.5%	0.69 [0.49, 0.97]	
Asker 2022, Shoulder	-0.821	0.2127	199	212	6.4%	0.44 [0.29, 0.67]	
Azuma 2020	-0.7133	0.1573	64	60	8.0%	0.49 [0.36, 0.67]	
Emery 2020	-0.3349	0.1914	566	501	7.0%	0.72 [0.49, 1.04]	
Farhan 2017	-0.811	0.4662	25	25	2.5%	0.44 [0.18, 1.11]	
Hasebe 2020	-0.1312	0.7516	156	103	1.1%	0.88 [0.20, 3.83]	
Hilska 2021	-0.1985	0.1264	673	730	8.9%	0.82 [0.64, 1.05]	
Hislop 2017	-0.0379	0.0869	1325	1127	9.9%	0.96 [0.81, 1.14]	+
Longo 2012	-0.8196	0.4002	80	41	3.1%	0.44 [0.20, 0.97]	
Owoeye 2014	-0.5276	0.1983	212	204	6.8%	0.59 [0.40, 0.87]	
Richmond 2016	-1.204	0.233	353	372	5.9%	0.30 [0.19, 0.47]	
Sakata 2019	-0.6636	0.2557	109	110	5.4%	0.51 [0.31, 0.85]	
Suzuki 2022	-0.3079	0.1288	37	34	8.8%	0.73 [0.57, 0.95]	- <b>-</b> -
Walden 2012	-0.0834	0.2097	2479	2085	6.5%	0.92 [0.61, 1.39]	
Zouita 2016	-1.198	0.7335	26	26	1.2%	0.30 [0.07, 1.27]	
Total (95% CI)			6989	6123	100.0%	0.63 [0.53, 0.74]	•
Heterogeneity: Tau <sup>2</sup> = 0.06; Chi <sup>2</sup> = 46.35, df = 16 (P < 0.0001); l <sup>2</sup> = 65%							
Test for overall effect: Z	= 5.57 (P < 0.000	0.1 0.2 0.5 1 2 5 10					
		,					Favours SIPP Favours Control

Figure 2 Forest plot showing the effect of SIPP on IRR of adolescents.

#### Systematic review

Intervention Control Rate Ratio Rate Ratio log[Rate Ratio] SE Total Total Weight IV, Random, 95% CI IV, Random, 95% CI Study or Subgroup 1.1.1 Lower Extremity Achenbach 2017 168 17% -0 2487 0 5864 111 0.78 [0.25, 2.46] Asker 2022. Knee -0.3711 0.1746 216 212 7.5% 0.69 [0.49, 0.97] 0.44 [0.18, 1.11] Farhan 2017 -0.811 0.4662 25 25 2.5% Hasebe 2020 -0.1312 0.7516 156 103 1.1% 0.88 [0.20, 3.83] Hilska 2021 -0.1985 0.1264 673 730 8.9% 0.82 [0.64, 1.05] Walden 2012 -0.0834 0.2097 2479 2085 6.5% 0.92 [0.61, 1.39] <sup>5%</sup> 0.78 [0.66, 0.93] <sup>12%</sup> 0.65 [0.52, 0.81] <sup>12%</sup> 0.65 [0.52, 0.81] <sup>12%</sup> 0.49 [0.36, 0.67] <sup>13%</sup> 0.72 [0.49, 1.04] <sup>13%</sup> 0.73 [0.57, 0.95] <sup>13%</sup> 0.30 [0.19, 0.47] <sup>13%</sup> 0.30 [0.19, 0.47] <sup>13%</sup> 0.30 [0.17, 1.27] <sup>14%</sup> 0.51 [0.31, 0.65] <sup>15%</sup> 0.47 [0.34, 0.65] <sup>15%</sup> 0.47 [0.57, 0.56] <sup>15%</sup> 0.47 [0.57, 0.56] <sup>15%</sup> 0.47 [0.53, 0.74] <sup>15%</sup> 0.53 [0.53, 0.74] <sup>15%</sup> 0.47 [0.58] <sup>15%</sup> 0 Subtotal (95% CI) 3717 3266 28.2% 0.78 [0.66, 0.93] Heterogeneity: Tau<sup>2</sup> = 0.00; Chi<sup>2</sup> = 2.75, df = 5 (P = 0.74); l<sup>2</sup> = 0% Test for overall effect: Z = 2.76 (P = 0.006) 1.1.2 All Åkerlund 2020 -0.4308 0.1139 301 170 9.2% -0.7133 0.1573 Azuma 2020 64 60 8.0% Emery 2020 -0.3349 0.1914 566 501 7.0% Hislop 2017 -0.0379 0.0869 1325 1127 9.9% Longo 2012 -0.8196 0.4002 80 41 3 1% Owoeye 2014 -0.5276 0.1983 212 204 6.8% Richmond 2016 372 -1.204 0.233 353 5.9% Suzuki 2022 -0.3079 0.1288 37 34 8.8% Zouita 2016 -1.198 0.7335 26 26 1.2% Subtotal (95% CI) 2964 2535 60.0% Heterogeneity: Tau<sup>2</sup> = 0.09; Chi<sup>2</sup> = 35.79, df = 8 (P < 0.0001); l<sup>2</sup> = 78% Test for overall effect: Z = 4.18 (P < 0.0001) 1.1.3 Upper Extremity Asker 2022. Shoulder -0.821 0.2127 199 212 6.4% Sakata 2019 -0.6636 0.2557 109 110 5.4% Subtotal (95% CI) 308 322 11.9% Heterogeneity: Tau<sup>2</sup> = 0.00; Chi<sup>2</sup> = 0.22, df = 1 (P = 0.64); l<sup>2</sup> = 0% Test for overall effect: Z = 4.63 (P < 0.00001) Total (95% CI) 6989 6123 100.0% Heterogeneity: Tau<sup>2</sup> = 0.06; Chi<sup>2</sup> = 46.35, df = 16 (P < 0.0001); l<sup>2</sup> = 65% Test for overall effect: Z = 5.57 (P < 0.00001)

Test for subgroup differences:  $Chi^2 = 8.66$ , df = 2 (P = 0.01), l<sup>2</sup> = 76.9%

Figure 3 Forest plot showing subgroup analysis on intervention focus of SIPP.

and upper-extremity SIPP subgroup while the studies in the all injuries SIPP subgroup had a high amount heterogeneity  $(I^2)$ =78%). Therefore, this subgroup analysis may explain the substantial heterogeneity in the overall analysis, where it is possibly due to the variety and differing definition of injuries measured by some of the studies.<sup>68</sup>

#### Sensitivity analysis

Sensitivity analysis was attempted but there was no significant change in heterogeneity ( $I^2$  %) observed when any single study was removed.

#### **Publication bias**

Visual inspection of the funnel plot plotted (online supplemental file 2:appendix G) suggested that there is a possibility of publication bias as there is a slight asymmetry. The larger-size studies were clustered symmetrically at the top around the mean effect size line, but it appears that smaller-size studies that show no protective effect of SIPP are missing.<sup>6</sup>

#### Narrative summary

The secondary outcome of investigating the effect of player compliance to SIPP on injury rate was summarised using narrative synthesis as statistical pooling was not possible. Three studies examined this and all concluded that compliance is key to the effectiveness of SIPP in reducing injury rate.<sup>50 55 57</sup> Two

they will see the need for and the benefit of such SIPP.<sup>62</sup> <sup>64</sup> They often find SIPP boring and irrelevant to their sports and training.<sup>61 65</sup> It often takes personal experience with injury for them to understand and be motivated to adopt it.<sup>60 65</sup> (refer to online supplemental file 2:appendix H)

#### Synthesised Finding 2: coaches/teachers are the key SIPP deliverers

Coaches and teachers are the key deliverers of SIPP (table 1) as they are the on-the-ground facilitators who spend the most

Systematic review

The sisce i maining 2. Couches/ teachers are the key sh	rr uenverers	
Categories	Number of findings	Key represented illustrations
Jnmatched influence over players as key on-the- ground facilitators	11	'I didn't care that muchbecause my [prior] coach didn't make it seem like a big deal, so I was like, 'Why should I care if she doesn't?' And then I would, after games, I'd feel very sore in my body and everything felt tight, and it's because I wouldn't stretch. And I didn't realize that because no one tolo me, and then [Coach X] pretty much, because he put so much emphasis on it, I was like, it's important [player]
		'If coaches aren't observant(and) you walk away(players) won't do (the warm-up)'
		'(Coach) puts a big emphasis on itHe makes sure we do it rightyou have the right formPays clo attention to the little details, tooOur coach usually gives a really good explanation, like, 'Oh, yeah this is what it really does,' and what's it's working out, and this, or it doesn't do this or this. He usual explains why we're doing everything.' (player)
ontrol over the structure of training programme	7	'I also feel like it's mostly the coaches, because they're the ones who implement the time structure to the practice, like, 'We're doing this for this amount of time.' So, it's like, if they give us the time to d it, we're going to do it.' (player)
		'I think they're (players) invested in rugby and do the warmup because Mr (Smith) tells them they've of to do the warmup.' (ID: 007)
		'Sometimes it (warm-up) is compulsory, and so you need to do some to avoid being scolded (by teachers)' (F, G1).
elief in the benefits and priority of implementing SIPP (Coaches buy-in)	10	I could be more alert and take this more seriously if I was even more convinced that this (using Knee Control) was important, then I probably would make more of an effort (C6)
		'warmup is probably the last thingl think about in my thought of what we need to do.'(coach)
		'it works super well with what we need to do as a warm up but I definitely think they get mor (than) just injury prevention out of it they are really warmed up to I've noticed a difference between the classes who had done the warm up just the difference in their technique and stuff.
Self-Efficacy in delivering the SIPP	3	'I don't have background training in PE, so it was a bit, sort of more difficult for me to feel confide in how to teach certain exercises'
		' don't think I do a good enough job of explaining exactly what we're stretching correctly, of demonstratingwhat we're doing—(the) correct form and all that.'(coach)
Awareness of SIPP and seeing the need for it	6	'I don't feel like Activate is shouted about enough. I don't think that many coaches that I've seen over the years know about it. (ID: 006)' 'and then the sprains, you just () look at the game and run and then there's a pit in the grass an you may suffer a sprain. I think there is nothing you can do to prevent it, it happens, it's part of the game (C14)'
		'I think the thing is that we, we are aware that girls easily injure their knees, and we have some girls whose older sisters had severe injuries, which motivates us to keep doing this (use Knee Control) to prevent injuries and to strengthen their bodies so that they won't have any issues in the future, that' what drives us to use it (C10)'

time with the players and have direct influence over them.<sup>62 64 65</sup> Coaches also have full control over the structure of the training programme, so how they carry out the SIPP in training and how much emphasis, effort they put in and time they allocate makes a big difference in the eventual effect of the SIPP.<sup>59 60</sup> For coaches to prioritise SIPP and implement it well, they must be aware of the existence of such programmes, believe in the importance and effectiveness of SIPP for their players and have sufficient selfefficacy to implement SIPP properly.<sup>61-63</sup> Coaches' motivation directly influences player motivation.<sup>62</sup>

support are crucial to the successful implementation of SIPP It is crucial that there is a readiness for implementation of SIPP from the top-down where the organisation (club, federation, etc) shows commitment to facilitate the implementation through various ways, such as endorsing the SIPP and making a directive to implement it.<sup>59 64 65</sup> Other ways include actively publicising and promoting SIPP to various stakeholders and providing training and resources for coaches to improve their knowledge and self-efficacy regarding SIPP.<sup>61 62 65</sup> Organisations should also

Synthesised Finding 3: organisational commitment and

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consider making injury prevention education a mandatory part of coaching education to really effect a change in attitude among coaches.<sup>59 64</sup> (refer to online supplemental file 2:appendix I)

# Synthesised Finding 4: the characteristics of the SIPP itself influence the adoption and use of the programme

The characteristics of the SIPP also affect its adoption by coaches and players. It is crucial for SIPP to be adaptable and modifiable to suit the needs of different sports and contexts.<sup>63 65</sup> The opportunity for coaches to be creative and integrate SIPP exercises into game drills will make it more fun and engaging.<sup>59 61 64</sup> For SIPP to be attractive, it has to be easy to implement and requires minimum time and effort or any additional resources, lowering the barrier to adopting or implementing it.<sup>59 62 63</sup> (refer to online supplemental file 2:appendix J)

#### Mixed-methods integration of evidence

Synthesised finding 2 (coaches are key facilitators) and 3 (organisational support is crucial) explained why the demonstrated efficacy of SIPP in reducing injuries found in the main meta-analysis is not translated to practice.<sup>18</sup> All the studies analysed were conducted under RCT conditions which are ideal and highly controlled, where most had experts conducting mandatory prestudy workshops and training for the coaches and players on the proper use of SIPP which is equivalent to organisational support and training to improve knowledge and self-efficacy.<sup>70</sup> This is shown by synthesised findings 2 and 3 to be major facilitators of SIPP implementation. Additional resources like pamphlets and video instructions were also provided to the coaches in many of the studies while some even had physiotherapists to facilitate and provide feedback for sessions. All these were factors identified by the qualitative synthesis to improve the implementation and effectiveness of SIPP but not implemented often enough in practice.

Narrative synthesis finding regarding player compliance is congruent with synthesised finding 1 (players' perceptions and beliefs) as young adolescent players often do not see the need for SIPP due to their 'sense of invincibility' and soon find SIPP boring and irrelevant, explaining the decrease in compliance over the season.

While the subgroup analyses for duration of SIPP and implementation strategies were not statistically significant, there was indication that shorter SIPPs ( $\leq 15 \text{ min IRR}=0.61 \text{ vs} > 15 \text{ min IRR}=0.66$ ) and those with implementation strategies (work-shop+supervision IRR=0.54 vs workshop IRR=0.67 vs no strategy IRR=0.72) were potentially more efficacious (online supplemental file 2:appendix F) and is supported by synthesised findings 3 and 4.

#### DISCUSSION

This review synthesised findings from 23 studies to examine the efficacy of SIPPs in reducing injury rates in adolescents and understanding the translation of this efficacy to real-world settings. The Translating Research into Injury Prevention Practice (TRIPP) framework is used to provide a comprehensive understanding of the current adolescent sports injury prevention literature and how this mixed-methods systematic review contributes and advances it<sup>71</sup> (table 2). Since the most recent meta-analysis in 2016 by Soomro *et al*,<sup>11</sup> there have been 13 newly published RCTs. Therefore, the quantitative aspect of our research was performed on the most recent decade of RCTs to include all these RCTs and update TRIPP Stage 4 with the most current evidence on the protective efficacy of all types of exercise-based SIPP in adolescents in all sports. The findings of our research revealed a significant overall protective effect of exercise-based SIPP in adolescents, where the injury rate was reduced by 37%. This is similar to results from previous meta-analyses both on adolescent team sports by Soomro *et al*<sup>11</sup> (exercise-based SIPPs) and Emery *et al*<sup>6</sup> (neuromuscular SIPPs), which found an estimated 40% and 36% reduction in all injuries and lower extremity injuries, respectively.

When compared with findings from previous related systematic reviews that looked at either different age groups or types of SIPPs, the efficacy of SIPPs demonstrated in reducing injury rates is consistent. For example, the meta-analysis by Ding *et*  $al^{17}$  looked at the effectiveness of warm-up-only interventions in reducing sports injuries in adolescents and children in 2021 and found an estimated 36% reduction in injury rate. Likewise, Rössler *et al*,<sup>4</sup> which combined data from RCT and nonrandomised study designs, concluded that exercise-based SIPPs can reduce injuries by around 46%. Therefore, our research reaffirms TRIPP stage 4 evidence on the benefits of long-term application of SIPP on reducing injury rates in adolescents, matching findings from systematic reviews examining that in the general population.<sup>67 72 73</sup>

Strong evidence base of TRIPP stage 4 alone is insufficient to change the sports injury landscape in adolescents as RCTs are carried out in highly controlled environments that are not reflective of actual implementation contexts.<sup>70 74 75</sup> For adoption and compliance in the community to improve, there is a need to understand the implementation issues that exist in the specific context, and this is best done through qualitative research on SIPP implementation in adolescents (TRIPP stage 5).<sup>6 32</sup> However, there has not been any reviews that synthesised and consolidated such research and thus, the qualitative aspect of our review fills this gap in the literature.

# Using ecological model and TRIPP framework to interpret mixed-methods evidence on SIPPs and improve real-life impact

Akin to numerous implementation science research done on sports injury prevention in the general population,<sup>32 75 76</sup> it is evident from the integrated findings that engagement of various stakeholders at multiple ecological levels is key to improving adoption and maintenance of SIPPs in adolescents. However, for this population, interpretation of the findings should be additionally guided by the ecological model proposed by Emery *et al*<sup>77</sup> as it incorporates the perspectives of multiple stakeholders and assigns a hierarchy of responsibility for the stakeholders in the implementation of SIPPs (table 2).

# Top-down approach is most optimal for SIPP implementation in adolescents

Despite the multitude of evidence supporting the implementation of SIPP in adolescents, there is still a lack of awareness of these SIPPs among coaches and players worldwide,<sup>6</sup> which is the first step of the awareness-to-adherence model by Pathman *et al*<sup>78</sup> for behaviour change.<sup>75</sup> In this ecological model, adolescents bear the lowest responsibility even though they are the beneficial end-users as they are deemed not cognitively developed enough to take full responsibility for their own safety in sports.<sup>1</sup> In contrast, organisations like national sports governing bodies and clubs at the top of the hierarchy who have the power to effect the most change will bear the most responsibility. Therefore, it is optimal to start from the top (synthesised finding 3) as successful implementation of SIPPs especially in adolescents



TRIPP, Translating Research into Injury Prevention Practice .

relies heavily on organisational commitment and structures and resources being put in place to support the delivery of SIPPs.

Organisations are found in several studies included to be best positioned to drive changes to this as they are the ones with the reach to disseminate information and the resources to develop and provide SIPP training, raising awareness of SIPP among the stakeholders. They even have the option to mandate injury prevention training as part of coaching education, along with supporting it with directives that require coaches to implement SIPP as part of training sessions. Such emphasis and commitment to implementation from governing bodies will have downstream effect on all the stakeholders from clubs to coaches (improved awareness and self-efficacy) and the players (SIPP is normalised as part of training), improving implementation. The higher than usual implementation rate of Prep-to-Play PRO in women's Australian Football<sup>76</sup> and FIFA 11+ in Switzerland soccer clubs<sup>79</sup> where both had the governing organisation's full commitment and support are some examples of this impact. This is congruent with general implementation research that has long highlighted organisation and leadership as core drivers of effective implementation.80

#### Coaches are key delivery agents

In addition, coaches have proven to be key delivery agents of SIPP due to their unparalleled influence over adolescents and their training programmes, consistent with findings from studies on coach education used in the BokSmart Safe Six SIPP.<sup>81 82</sup> A scoping review by Guilfoyle et  $al^{83}$  on coaches' role in youth SIPPs supported our findings that coaches' competency in delivering SIPP (self-efficacy) and their belief in the value of SIPPs (buy-in) are the two main factors that promote the implementation. Therefore, both the literature and our integrated findings found that organisations need to constantly support coaches with resources and trainings like workshops which will not only improve their confidence in delivering SIPP (self-efficacy) but also educate them on importance of SIPPs to create buy-in (behaviour change).<sup>76 84</sup> This helps facilitate sustained implementation.<sup>83</sup>

Furthermore, coaches' willingness to integrate SIPP into training by prioritising and allocating more training time to SIPP will often influence players' own thoughts and habits in using SIPPs. This aids in their own long-term compliance to SIPP which tends to decrease over a season.

These findings illustrate how a top-down approach starting at organisations will maximise implementation efforts in a target population that is young and impressionable.<sup>85</sup>

#### Nature of SIPP

data mining Outside of the ecological model, the nature of the SIPP is another key factor in the implementation. Coaches in the community for this age group vary greatly in expertise and experience, and also differ in commitment level (from full-time professional to parttime voluntary).<sup>32 86</sup> Hence, it is important for SIPP to be userfriendly and easy to implement where not a lot of resources are required and exercises not too difficult or long. However, it is also important for SIPPs to be adaptable in nature to cater to a range of contexts and different end-users.<sup>32</sup> Adaptability of the exercises allows coaches to adjust and progress according to the evolving needs of the team/individual. It also makes SIPP more engaging when coaches are able to integrate it into drills and technologies. game skills which is important as adolescents do not always see the necessity for SIPP and finds it boring.

#### **Strengths and limitations**

This review has a few limitations. First, there is rather substantial heterogeneity in the included studies, possibly due to the methodological variations in the nature of participants, outcomes measured due to different definitions of sports injury and types of intervention in the studies included. Moreover, non-English studies were excluded which may have led to potential bias and a date limit of 10 years being set could have excluded some older qualitative studies.

To the best of our knowledge, this review is the first in the field that integrated TRIPP stages 4 and 5 (table 2),<sup>71</sup> corroborating the most rigorous up-to-date scientific evidence on the protective

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Table 3 RE-AIM Sports Setting Matrix (RE-AIM SSM) adapted from Finch and Donaldson <sup>70</sup>												
	Level of assessment/intervention setting or target											
	State/Provincial sporting Team/											
<b>RE-AIM Dimensions</b>	National sports governing body	organisation	Regional league or association	Club	Coach	Participants						
<b>R</b> each												
Effectiveness												
Adoption												
Implementation												
Maintenance												
The table shows all possible intervention points, but relevance depends on context and intervention target.												

efficacy of SIPP with insights into the specific implementation of SIPP in adolescents, promoting evidence translation.<sup>19</sup>

#### Direction and implications for future research

Since this review has synthesised both TRIPP stages 4 and 5 evidence, it advances adolescent sports injury research to the next stage, which is to focus on implementation science and evaluate the effectiveness of SIPPs in uncontrolled 'real-world' settings with implementation strategies applied to obtain more representative results of the impact of SIPPs in reducing injury rates in adolescents.<sup>70 75</sup> This is done through TRIPP stage 6 effectiveness studies that the current literature lacks.<sup>71</sup> Thus, our findings help researchers to develop context-specific implementation strategies in partnership with relevant stakeholders and be used in such studies.<sup>75</sup> TRIPP stage 6 studies should also consider using the Reach Effectiveness Adoption Implementation Maintenance Sports Setting Matrix (RE-AIM SSM) (table 3) as it provides a framework<sup>70</sup> to navigate the complex multilevel nature of SIPP implementation,<sup>75</sup> guide the planning of appropriate strategies and thoroughly evaluate the impact of SIPPs across the entire hierarchy of stakeholders.<sup>70</sup> <sup>77</sup> The mixed-methods study by Bruder *et al*<sup>76</sup> on SIPP for women's elite Australian Football provides a great example of this.

Lastly, there should be a development of a consensus statement on the reporting standards for SIPPs where injury definition, exposure monitoring, assessment of outcome etc. are standardised to ensure homogeneity in study design. This would help in identifying moderating factors and a clearer interpretation of results.

#### CONCLUSION

The efficacy of SIPP in reducing injury rates in adolescents is reaffirmed by the past decade of research but translation of this efficacy to 'real-world' effectiveness is impaired by poor adoption and compliance in the community.<sup>74</sup> Synthesising qualitative findings on the implementation of SIPP in adolescents and integrating it with the quantitative results through the convergent segregated approach provided many valuable insights, indicating that key stakeholders at multiple ecological levels (organisations, coaches, players) need to be engaged to drive implementation. Due to the hierarchy of responsibility for stakeholders involved in adolescent SIPP implementation, employing a top-down approach by targeting organisations (governing bodies) first as they are best positioned to support and drive change, followed by coaches (delivery agents) through increasing competence and buy-in and then players (end-users) would be the most optimal and allows for downstream effects.<sup>23 77 85</sup> Meanwhile, the adaptability and user-friendliness of SIPPs are also crucial in improving implementation. Future effectiveness studies evaluating SIPPs in 'real-world' contexts is the last part of the research process in achieving the ultimate goal of improving adoption and maintenance of efficacious SIPP in respective sporting communities to yield the full benefits of SIPPs and thus sports.<sup>7175</sup>

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#### ORCID iDs

Zhe Xin Zhang http://orcid.org/0009-0009-2026-8745 Joseph Lai http://orcid.org/0009-0009-6336-7137 Liang Shen http://orcid.org/0000-0001-7976-668X Lingaraj Krishna http://orcid.org/0000-0001-7083-7242

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